INNOVATIVE CONCEPT OF GEARLESS BI-FREEWHEEL DIFFERENTIAL MECHANISM

Chandan Saxena, Chandra Shekhar Malvi
Mechanical Engineering Department, Madhav Institute of Technology & Science
Racecourse Road, Gwalior, INDIA

Abstract- A differential is a device that allows a difference in velocity (and displacement) between two elements. This requires a 2-DOF mechanism such as an epicyclic gear train. Perhaps the most common application of differentials is in the final drive mechanisms of wheeled land vehicles. The main aim of this paper is to introduce an Innovative concept of Gearless Bi-Freewheel Differential Mechanism. Its design and Stress Analysis on the CAD model prepared for its behaviour under different loads. Analysis is performed on different materials of shaft (intermediate rod), Carbon Steel and aluminium alloys. Whereas, use of carbon steel is common nowadays. Stress, displacement is analysed by considering weight reduction in the differential. The analysis is done in Inventor Professional software. In this particular work, all parts of differential assembly are designed and analysed under static condition and then modelled. Corresponding required data is taken from data books, standard results and journal papers. Detailed drawings of all parts are also shown. This paper thus suggest the use of aluminium alloy in order to minimise the weight of the differential. Introducing the new concept of differential will help to improve the performance of light weight vehicles and also makes possible to use differential mechanism where it is not adopted due to its larger weight and cost.

Keywords: Differential, freewheel, Gearless, BFD

Introduction

A Differential is a two-DOF device. Two inputs are needed to obtain a predictable output. In some cases, such as the automotive differential, one input is provided (the driveshaft) and two frictionally coupled outputs are obtained (the two driving wheels). In other applications such as automatic transmissions, aircraft engine to propeller reductions, and in-hub bicycle transmissions, two inputs are provided (one usually being a zero velocity, i.e., a fixed gear), and one controlled output results. The Basic limitation of Conventional and Traditional Differentials is accompanied by their comparative large cost and masses. This confines the application of these differentials to the cases, only where either requirement is must (or in case where compactness of transmission system is not necessary) or when economy is not a problem. However main objective of differential is to sort-out the basic problem of relative angular speed of different ends of a shaft which have also to rotate at same speed at different circumstances. This case may occur in a machine or may come up in a vehicle when it has to go through a turn or when it is on a rough surface while in drive or even on steering at very high speeds. Secondly, conventional differential may also suffers operational problems when traction is not same on both of wheels. This generally happens when one wheel does not have enough traction or have a different traction as that of other wheel, such as when it is in snow or mud. The end with lesser traction will rotate by slipping without utilizing torque of main drive and the opposite wheel will stay still (or rotate at normal speed) so that the vehicle may not move or simply slide.

This is the exactly where requirement of such a differential arises which could overcome the limitation of its traditional forms which could allow the differences in angular speed and also avoid the involvement of weighted gears and casing and separate shafts and axles.

Methodology

Most important element of BFD (bi-freewheel differential) is freewheel obviously. Two freewheels are placed at the end of intermediate shaft as shown such that the hollow shaft is welded to the outer wheel of freewheel only. One important point that must be noted that both freewheel must be placed such that they may transmit the torque in same direction only. For satisfying this condition, they must be placed as inverted with respect to each other. Then end rods are essentially connected to the inner part by means of welding (or may be bolted or screwed up) as shown in assembly picture. This end rod is that element of the
differential on which wheels may be mounted. Wheel may be directly mounted on the end of these end rods.

![Figure 1 (a). Freewheel](image)

**Functional Description**

Basic concept of operation of a Bi-freewheel Gearless Differential is based on the working principle of a Freewheel. A Freewheel is a torque transmitting mechanical device which operates only in one direction. This component thus is used in pedalling cycle where torque has to be transmitted only in one direction, and never in opposite direction.

![Figure 1 (b). Intermediate Shaft](image) ![Figure 1 (c). End Rod](image)

Explanation of the operation of BFD (Bi-Freewheel Differential has to be initiated with the explanation of operation of freewheel. A typical freewheel may be assumed to be consist of two parts, inner and outer one (figure 1 (a), shows two parts separately with different colours).

The inner part of Freewheel, on keeping the outer part stationary, transmit the torque in counterclockwise sense, while on keeping the inner wheel stationary, outer part rotate freely in the same counterclockwise sense.

In the same way, inner part will transmit the torque in clockwise sense only when keeping outer part stationary. While outer part rotate freely in same clockwise direction when keeping inner part stationary.

Above explanation forms the basis of functional operation of Bi-freewheel Differential, which has main components: An intermediate shaft (basically a hollow rod, just named ‘shaft’ as it transmit This way same angular speed difference may be developed by BFD also. This way BFD facilitate easy power), two freewheels, two end rods and two bearings (or plummer blocks) for the support. Intermediate shaft is mechanically coupled with driving shaft or chain or belt. This may be any power transmitting mechanism as suitable for the purpose. But essentially, the direction of driving medium to intermediate shaft must be same as that of the torque transmitting direction of both freewheels.

Taking a practical instance, considering a case when a car with BFD is driving on a straight road. This is the time when wheels are required to rotate at exactly same angular speed. At this time, intermediate shaft speed will be synchronized with the speed of driving shaft. As the torque transmitting direction of both freewheels are also same, intermediate shaft will take both of the end rods with it at the same speed, thus efficiently providing straight line motion to the car.

Now considering a case of turning of that car, say right. Obviously left wheel will be required to rotate at comparative higher speed. Recalling the case when outer part of freewheel was fixed, inner wheel can rotate freely in direction of torque transmission. This will happen with left wheel, and it will rotate at some speed say ‘n rpm’ with respect to intermediate shaft (intermediate shaft is mechanically coupled to outer part of freewheel thus relative speed between both is 0 rpm) which is actually rotating at speed of driving shaft say ‘N’. This will net rotation of left wheel at ‘n + N’ speed, while right wheel is continuing to rotate at ‘N’ speed (same as that of intermediate shaft). Thus BFD results in a net difference of speed between two wheels equal to ‘n’, while Geared Differential result a net difference of ‘2n’ due to opposite rotation of both wheels with net speed of ‘n’.

Setting an example of practical interest, suppose a car is moving on a straight road at some speed and its wheel are rotating at 2000 rpm (N rpm). Now it came on a right turn where a net difference of 250 rpm (2n rpm) is required as according to turning radius and wheel dia. Now traditional differential may develop this difference by rotating both wheels by125 rpm in opposite direction i.e.

Left wheel = 2125 rpm (N + n rpm)
Right wheel = 1875 rpm (N - n rpm)
Total Difference = 2125-1875= 250 rpm (2n rpm)

But BFD may obtain this same as follows:

Left wheel = 2250 rpm (N + 2n rpm)
Right wheel = 2000 rpm (N rpm)
Total Difference = 2250-2000= 250 rpm (2n rpm)

steering of racing type cars with high speed and light weight.
Analysis

Analysis is performed on designing software Autodesk Inventor Professional 2014.

Results Generated by software on application of 800 N on each end rod
Analysis is performed by applying 800N on each end rod (Total 1600N) under static condition, and following conditions.

- Intermediate Shaft Material – Steel Carbon
- Freewheel Load Capacity
- Bearing Material – Stainless steel
- End Rod Material – Austenitic Stainless Steel

Following results are obtained:
- A minimum factor of safety obtained is 5.3.
- Maximum and minimum 1\textsuperscript{st} principle stress is 47.71MPa and -19.94MPa respectively.
- Maximum and minimum 3\textsuperscript{rd} principle stress is 11.43MPa and -69.76MPa respectively.
- Maximum Displacement = 0.05985 mm at free end.
- Maximum factor of safety obtained is 15.

Thus obtained data verifies successful and safe operation of BFD especially for small vehicles like racing vehicles or for many mechanical purposes.

**Conclusion**

Achieved Factor of safety as shown in figure (minimum) of 5.3 with each force of 800 N and end rod material of austenite stainless steel and maximum achieved factor of safety of 15 proves a successful implementation of BFD in actual practises. Bi-freewheel Differential may replace the traditional differential on some account where place, weight and cost matters but also at the same time during its operation on turning it will transfer torque only on inner wheel which limits its application to small and light-weight vehicles only like in carts, 3-wheelers, wheel-chair, formula-one etc. Phrase: Every new concept leads toward even great Inventions.

**References**

2. “Theory of Machines” by S.S. Rattan
3. “Design data Book” by PSG College of Technology

Revised